


Review

Digital Manufacturing Platforms in the Industry 4.0 from Private and Public Perspectives

Jon Kepa Gerrikagoitia [1,*], Gorka Unamuno [1], Elena Urkia [1] and Ainhoa Serna [2,*]

[1] IDEKO, ICT and Automation Research Group, Arriaga 2, 20870 Elgoibar, Spain
[2] Digital Manufacturing Group, Universidad de Deusto, Pozoa Kalea, s/n, 01013 Vitoria-Gasteiz, Araba, Spain
* Correspondence: jkgerrikagoitia@ideko.es (J.K.G.); aserna@deusto.es (A.S.)

Received: 21 June 2019; Accepted: 19 July 2019; Published: 23 July 2019



Abstract: The fourth industrial revolution is characterized by the introduction of the Internet of things (IoT) and Internet of Services (IoS) concepts into manufacturing, which enables smart factories with vertically and horizontally integrated production systems. The main driver is technology, as Industry 4.0 is a collective term for technologies and concepts of value chain organization. Digital manufacturing platforms play an increasing role in dealing with competitive pressures and incorporating new technologies, applications, and services. Motivated by the difficulties to understand and adopt Industry 4.0 and the momentum that the topic has currently, this paper reviews the concepts and approaches related to digital manufacturing platforms from different perspectives: IoT platforms, digital manufacturing platforms, digital platforms as ecosystems, digital platforms from research and development perspective, and digital platform from industrial equipment suppliers.

Keywords: digital manufacturing; smart factory; Industry 4.0; digital platforms

---

1. Introduction

The Industry 4.0 concept has gained a global context beyond the German Industrie 4.0 initiative and suggests a perspective of the fourth industrial revolution that brings ICT (Information and Communication Technologies) into manufacturing that aims at the development of smart factories with fully integrated production systems. Among the different Industry 4.0 definitions, there is a common understanding that Cyber-Physical Systems (CPS), Internet of Things (IoT), Big Data Analytics, and Internet of Services (IoS) are the main components that embody Industry 4.0 [1,2]. Besides the technological perspective, Industry 4.0 can be understood as a collective term for technologies and concepts of value chain organization [3]. As a result, in industries worldwide, highly flexible processes that can be changed quickly enable individualized mass production [4].

Within modularly structured Smart Factories, Cyber Physical Systems (CPS) monitor physical processes, create a virtual representation of the physical world, and make decisions. The traditional structure of the automation pyramid and the IT/OT (Information Technologies/Operational Technologies) frontiers are blurring, CPS enable new means of communication and cooperation among devices, production assets and information systems in an orchestrated and decentralized way in real time. Via the Internet of Services (IoS), both internal and cross organizational services are offered and used by stakeholders of the value chain.

Different countries and regions have designed their own programs to achieve this fourth revolution. For example, the German government and the European Union (EU) promote the Industry 4.0 program [5], while in the United States, the Smart Manufacturing Leadership Coalition (SMLC) is the main initiative [6]. Other important manufacturing countries such as Japan [7] and Korea [8] have also established national programs on smart manufacturing.

Economic expectations are also important, as PwC estimated a global investment in technologies for industry digitization in 2020 of more than $900 billion annually. It also reported that 72% of the companies that took part in the survey expected to have achieved “advanced levels of digitization” by 2020 [9]. There is a growing awareness in business communities regarding the market opportunity for platform suppliers based on the level of investment.

Focusing on Europe, in 2016, the European Commission started the Digitizing European Industry initiative (DEI) aimed to reinforce the EU’s competitiveness in digital technologies. The European Commission strategy defines four pillars: Digital Innovation Hubs, regulatory framework, skills, and Digital Platforms [10]. The EU has launched several calls in the Horizon 2020 program to advance in the development of digital industrial platforms like DT-ICT-07 2018–2019 and 2019–2020 with a budget over €100 M. Digital platforms for manufacturing play a key role in addressing competitive pressures and integrating new technologies, apps and services. The challenge is to make full use of new technologies that enable manufacturing businesses, particularly mid-caps and small and medium-sized enterprises (SMEs) to meet the requirements of evolving supply and value chains. Besides innovation and research actions there are also coordination and support Activities in order to cross-fertilize the industrial platform communities, facilitating the adoption of digital technologies from ongoing and past research projects to real-world use cases and encouraging the transfer of skills and know-how between industry and academia.

The first steps towards the digitization of the European industry were made in 2013 by an Industry 4.0 working group that published a report [5], which provided the vision, the integration features, the priority areas for action, and the example applications for the fourth industrial revolution. Nevertheless, there are still problems for its correct implementation and Industry 4.0 is tackling adoption issues argued by the literature, such as that Industry 4.0 is a complex concept which is not clearly understood yet by companies’ managers, the lack of a detailed roadmap, the need of strategic guidance and clear implementation details, the large IT investments required in order to achieve a vertical and horizontal integration, the uncertainty about the outcomes, and the maturity and capability of the companies [11–15].

The digital manufacturing platform scenario is complex and uncertain, as the main players and roles are still being shaped. Trying to foresee market scenarios, in December 2016. The Economist compared two platforms, the General Electric (GE) Predix and Siemens Mindsphere in order to evaluate the likelihood of finally dominating the industrial Internet. It found that it is unlikely that a single platform will reach complete dominance and highlighted the significance of an open strategy [16].

Motivated by the difficulties to understand and adopt Industry 4.0 and the momentum that the topic has currently, this paper reviews the concepts and approaches related to digital manufacturing platforms from a qualitative research methodology considering the period of the last five years, when it all started. The structure of the paper contains an introduction, the followed methodology, the results of the research classified in subsections as explained in the methodology, a conclusion section that states from a qualitative perspective the outcome of the review work, and the references.

The relevance and contribution of the paper relies to a great extent in the proposed review methodology approach that follows the view and motivation of a research organization specialized in manufacturing technologies and digital platforms that is part of a machine tool builder industrial group. Thus, the whole lifecycle of research, knowledge transfer to industry, funding sources and ROI (Return on Investment) for industrial partners are present in the rationale of the methodology.

The findings of the research work show the broad and complex scope of digital manufacturing platforms following the motivation and view of the authors. The relationship between private (IoT platform vendors, manufacturing equipment suppliers, and machine tool builders) and public stakeholders (European Commission, Public Private Partnerships, etc.) in the strategy of digitizing the European industry contributes to build a global vision towards addressing future challenges posed by the need to create new business models based on data economy and the growth of digital ecosystems fostered by digital manufacturing platforms.

2. Literature Review

The current concept of a digital manufacturing platform has had an evolution since its roots in the sixties when the concept of manufacturing systems came up with advances in computing capability. Since then, it has attracted the attention of researchers who reported their findings in the literature from different perspectives and viewpoints in the past years. This section will review this evolution covering the different terms, names, and features related with digital manufacturing platforms.

Chryssolouris et al. [17] describe the scope of digital manufacturing and show the evolution of information technology systems in manufacturing, outlining their characteristics and future trends. Digital manufacturing and digital factory concepts in the pre-industry 4.0 era focus mainly on PLM (Product Lifecycle Management) technologies as computer-aided design, engineering, process, product data and life-cycle management, simulation and virtual reality, process control, shop floor scheduling, decision support, decision making, manufacturing resource planning, enterprise resource planning, logistics, supply chain management, and e-commerce systems.

As results of digitization advancement, manufacturing system controls have to deal with materials and machines and integration issues that started to come up in manufacturing, as machines and devices in a manufacturing process were no longer isolated but parts of a system, where all the components could be effectively coordinated. To handle integration issues, computer-integrated manufacturing system (CIMS) are starting to be widely adopted by companies. In this context Chen et al. [18] study the perspectives and enablers of integrated and intelligent manufacturing. Increasing opportunities were opened by Internet of Things (IoT) and CPS technologies, which enabled integration to be made wider and more open, comprising three levels of integration in manufacturing—vertical integration, horizontal integration, and end-to-end integration [5].

According to Chen et al. [18] intelligent manufacturing platforms are the enablers to implement intelligent manufacturing technologies. The point of view of industries that are preparing to develop cloud computing platforms based on IoT motivated by business is explained. Predix [19], ThingWorx [20], and Siemens [21] software platforms are described as the main references by the authors. In addition, the authors remark that “digital twins” are a significant feature of all such platforms to allow for the prediction of future conditions of productive assets.

Alcácer et al. [22] show an approach of Industry 4.0 for manufacturing systems based on the Smart Factory concept. There is a clear focus on enabling technologies for Smart Factory, such as IoT, IoS, systems integration, and the Cyber-Physical Production System (CPPS). The presented Smart Factory concept relies heavily on distributed computing as a core concept of Industry 4.0, as opposed to the most common manufacturing environments that are centralized. Authors explain the connection between technologies and standards with the role of RAMI 4.0 and its importance in leading the growth of CPPS [23].

Zhong et al. [24] present a review of intelligent manufacturing in the context of Industry 4.0. The authors present the major advances in manufacturing technologies as intelligent manufacturing, IoT enabled manufacturing, and cloud manufacturing. They define intelligent manufacturing (also known as smart manufacturing) as a broad concept of manufacturing, with the purpose of optimizing production and product transactions by making full use of advanced information and manufacturing technologies [25]. Intelligent manufacturing system (IMS) are considered to be the next-generation manufacturing system by adopting new models, new forms, and new methodologies to transform the traditional manufacturing system into a smart system. Authors remark the importance of service-oriented architecture (SOA) via the Internet to that end, providing collaborative, customizable, flexible, and reconfigurable services to end-users. Moreover, the authors highlight the essential role of AI (Artificial Intelligence) in an IMS by providing features such as learning, reasoning, and acting in a human-machine cooperation context. IMS shape an ecosystem where manufacturing elements are involved with organizational, managerial, and technical implications.

Another technological aspect is cloud manufacturing [26] that refers to an advanced manufacturing model under the support of cloud computing, IoT, virtualization, and service-oriented technologies.

It covers the extended whole life cycle of a product, from its design, simulation, manufacturing, testing, and maintenance, aiming to provide on-demand manufacturing services can from the cloud.

De Reuver eta al. [27] approach the study of digital platforms and examine the ecosystems that surround them. The authors state that digital platforms have a transformative and disruptive impact on organizations and their business models to the extent that platforms change the power structure and the relationship between participants in the ecosystem. The way service providers and device manufacturers strategize in a platform environment is discussed based on prior ecosystemic thinking work [28], taking into account that organizations are not isolated anymore, and value is co-created and co-delivered by multiple contributing entities.

3. Methodology

The present research work follows a qualitative approach focusing on the broad concept of the digital manufacturing platform from the perspective of a research organization specialized in manufacturing technologies and digital platforms that is part of a machine tool builder industrial group. Thus, research and industry views are included in the review paper as they complement each other to reach research and business goals.

In order to cover the technological perspective, the first step was to understand which were the technology enablers that make possible the development of digital manufacturing platforms. The essential features of an IoT platform were well known considering the authors' background and the search was focused on the major IT (Information Technology) players that provide application enablement platforms for horizontal domains covering connectivity, data acquisition, data storage, device monitoring, data analysis, and data visualization capabilities. As the scientific literature in this field is not extensive so far, the data sources were mainly IT vendors' web sources and white papers combined with benchmarking articles among different solutions. Small and niche IoT platform vendors were also included in the search and additional sources, such as the Hannover Messe Fair from 2015 to 2018, were considered as well. The next step of the review method was to focus and search for manufacturing domain platforms and specifically the concept of digital manufacturing platforms. The sources were both research papers and documents from the European Commission, as the influence of policy making with the DEI (Digitization of the European Industry) strategy has had a remarkable impact in the reviewed topic. Following the impact, the next stage was to obtain the research initiatives and the main outcomes of the DEI regarding digital manufacturing platforms. In this case the main information sources were web sources containing European Commission documents and European research projects. The research and search was focused on the European Research and Innovation calls under the Horizon 2020 programs related to digital manufacturing. The last stage of the method was to include the strategy and approach carried out by industrial equipment suppliers and machine tool builders. The data sources used for that purpose were based on a competitive intelligence tool, INNGUMMA (Elgoibar, Spain), that allows to identify and monitor competitors under specific observation parameters.

4. Results

4.1. IoT Platforms

An IoT platform is a middleware between the IoT devices and IoT gateways on one hand and applications on the other hand. The IoT platform enables the building of applications and are also called Application Enablement Platforms or AEPs. The essential features and capabilities of an IoT platform are on the level of connectivity and network management, device management, data acquisition, security, event processing, monitoring, analysis, visualization, integration, storage, and application enablement.

There are several vendors with different architectures, ways of connecting and managing IoT devices, possibilities to manage and analyze data, capabilities to build applications, and options

to leverage IoT in a meaningful way for any given IoT use case in any given context—consumer applications, enterprise IoT applications, and Industrial IoT or Industry 4.0. In the end, IoT is part of an integrated approach to leverage data from devices and assets. There are hundreds of players in the market and although the IoT platforms have many functions in common there are differences in the offerings with sometimes very different features [28].

The main players in the IoT platform market are:

Microsoft Azure IoT [29]: The Microsoft Azure IoT offers device monitoring, rules engine, device shadowing, and identity registry. Upon these basic services, Azure IoT incorporates several existing products such as Stream Analytics, Power BI, IoT Hub, notifications hub, and some pre-packed machine learning. In addition, Azure Digital Twins allows to create digital models of any physical environment; including places, things, and people.

Oracle Internet of Things (IoT) Cloud Service [30] is a managed Platform as a Service (PaaS) cloud-based offering that allows to connect devices to the cloud, analyze data from those devices in real time, and integrate data with enterprise applications, web services, or with other Oracle Cloud Services, such as Oracle Business Intelligence Cloud Service.

Google Cloud IoT Core [31]: Google Cloud IoT Core is a fully manageable IoT platform. This platform is labeled as a major rival against the other similar platforms, since it mainly concentrates on intelligence. To achieve this intelligence, it utilizes ad-hoc queries using Google Big Query and Cloud Functions workflows. Thus, the devices can automate changes based on real-time events, data visualizations are done using Google Data Studio, and machine learning is done with Cloud Machine Learning Engine.

IBM Watson IoT [32]: This cloud IoT platform enables users to connect their devices and the IoT device data into a repository from where this cloud IoT helps them gain insight into an IoT network to not just improve their operations, but also launch various new business models. The users of this cloud platform receive real-time data exchange, data storage, device management, and secure communications.

AWS IoT Core [33]: This cloud IoT platform helps turn cars, sensory grids, and turbines to "smart" objects by helping in connecting and managing the sensors on these objects. The AWS IoT Core provides a secure device gateway, device shadows, device SDK, a registry for recognizing the different devices, a message broker, and rules engine that would evaluate the inbound messages.

Bosch IoT Suite [34]: This cloud platform is one with services designed to meet the requirements of every IoT project. The platform was initially designed and built to provide the IoT solution developers flexibility and ease to perform their daily tasks.

Above the mentioned IoT platforms there are large generic IoT cloud platforms from vendors such as IBM, Google, Amazon, Microsoft, and more. The so-called IoT network providers' platforms, such as AT&T and Orange Business Services, as well as Telefónica or Vodafone are another category of IoT platforms.

4.2. Digital Manufacturing Platforms

In the early stages of the digitization of the industry there were Remote Machine Monitoring systems (RMMS) that are machine manufacturer software products designed to allow their clients to monitor their shop floor equipment [35]. DMG Mori Seiki has been a pioneer with an RMMS solution called Mori Net that allowed customers to monitor their DMG Mori Seiki machines over a local network or the Internet. For non DMG MORI machines they developed a solution named Messenger that is based on MTConnect, a standard for accessing machine tool data [36,37].

The advent of the Internet of Things in the industry sector pushed the adoption of sensor-based information collection to address their key problems related primarily to machine downtimes and process delays. This way, machine monitoring evolves towards condition monitoring, which is the practice of monitoring electrical equipment, usually with external sensors, in order to gather the required data for diagnosis. To achieve this goal, data acquisition systems and data loggers are used to

monitor all kinds of industrial equipment and devices. A 2017 Research & Markets magazine study provides that the market for condition monitoring is almost $11 billion for factories and OEMs. Dell, Caterpillar, Microsoft, IBM, General Electric, and Siemens, among others, are industry leaders named in the study.

Besides condition monitoring, more types of services and requirements, such as preventive maintenance, runtime and uptime measurement, energy monitoring or performance tracking are coming up and as results Digital Manufacturing platforms are being shaped to cover a broader scope.

In this broader scope, the European Factories of the Future Research Association (EFFRA) that is a non-for-profit, industry-driven association is performing an important role in the digitization of manufacturing industry and digital manufacturing platforms. As an example of the activity under EFFRA's umbrella, the "Connected Factories" CSA (Coordination and Support Action) establishes a structured overview of available and upcoming technological approaches and best practices [38]. The project identifies present and future needs, as well as challenges, of the manufacturing industries. The digitization of manufacturing connects people, devices, machines and enterprises, and includes concepts such as 'Industrial Internet', 'digital manufacturing platforms', and the 'Internet of Things' (IoT). Moreover, the Connected Factories explores pathways to the digital integration and interoperability of manufacturing systems and processes and the benefits this will bring. Hence, Connected Factories will enhance the awareness among companies of the use of digital technologies in the manufacturing sector, but also provide them with expertise to make informed choices about technology and business models. Connected Factories will improve companies' understanding of the use of digital techniques in the manufacturing industry, and also provide them with expertise to make informed technology and company model decisions.

Digital manufacturing platforms allow the provision of manufacturing services in a broad sense [39]. Digital platforms provide services that can be used for data collection, storage, processing, and delivery. These data describe the whole context which includes the product that is being manufactured, the manufacturing process, the production assets, the worker, and the entire value network. In general, the digital platform for manufacturing can provide any "digital" extension of functionalities for physical assets, through the adoption of ICT technologies. Digital platforms play a crucial role in enabling the application scenarios of digital manufacturing [40]. All services are aimed at optimizing manufacturing from different perspectives such as efficiency, availability, quality, performance, flexibility, etc.

Digital platforms can be on premise, in the cloud or in a hybrid architecture. Nevertheless, the thrust into a productive environment includes the need for agreements on industrial communication interfaces and protocols, common data models, semantic models and the interoperability of data. RAMI 4.0 is a framework that will help accomplish this task [41]. RAMI 4.0 is a three-dimensional layer model that compares the life cycles of products, factories, machinery or orders with the hierarchy levels of Industry 4.0. The model divides existing standards into manageable parts, integrates different user perspectives, and provides a common understanding of Industry 4.0 technologies, standards, and use cases.

Digital Platforms as Ecosystems

A digital manufacturing platform is part of a layered architecture that integrates a set of functions or software services that can be implemented by different technologies using interfaces and making the data available to be consumed by third party applications [39]. For example, a platform could make available operational state and machining process data provided by a machine tool to be used in business intelligence applications that provide production or OEE (overall equipment efficiency) insights. Platforms can be understood as operating systems that offer a set of applications as services. These services make shop floor data (machines, products, operators, . . .) accessible to other software applications (production planning, operation and process, quality management, maintenance, troubleshooting, energy management, etc.). The services usually will be exposed using IT flavor open

standard interfaces, such as API Rest or OT standards such as OPC-UA. This way, an ecosystem of application developers can be fostered.

The digital manufacturing platform includes three characteristics. First, the community aspect that embodies an ecosystem of users in a social network connected to each other. In this community there is a marketplace where the offer and the demand can be matched. Some users are service providers, their raw material is data, and the offered product is usually a software app as a value-added data-driven service. The value creation relies on a solid technology infrastructure and this is the second aspect. The infrastructure aspect of the digital manufacturing platform is the enabler for users and partners to develop apps and create value added data-driven services. The ability to develop and deploy software apps in the platform is a core issue in order to develop a growing ecosystem of data-driven service consumers and producers. The infrastructure is the basic layer to boost the digital economy in manufacturing and to do so it is mandatory to be an open infrastructure that is able to integrate and unlock technologies and systems. The last aspect is the data role. Data is the raw material of digital manufacturing platforms provided by enterprise management systems, industrial assets, devices, and sensors and has to be exchanged, accessed, and processed in a proper way. The outcome of the process will be produced and consumed by allowed platform users.

Moreover, the ecosystem of digital manufacturing platforms is composed by four types of players. These are the owners of platforms in charge of the governance, the providers who are the interface with users, the producers who create their offerings, and consumers.

As the perception of date value is gaining importance in the global value creation, IDS (international data spaces) is devoted to forming the basis for data ecosystems and market places based on the principles of trust and data-sovereignty, which is guaranteed for data creators with respect to who is using their data, for how long, for which application, how many times, and according to which terms and conditions [42].

4.3. Digital Platforms from R&D Perspective

Digital manufacturing platform related initiatives have been fostered by Public-Private Partnerships (PPPs) at European level. Factories of the Future (FoF) (discrete manufacturing) and Sustainable Process Industry through Resource and Energy Efficiency (SPIRE) PPP (industrial processing) are two PPPs that explicitly address manufacturing/production [43].

Under the FoF PPP, a set of ten projects and one coordination and support action, called "Connected Factories" were started in autumn 2016 that develop reference implementations of platforms in a multi-sided market ecosystem and include user-driven proof-of-concept demonstrations and validation in several different scenarios [40]. The Connected Factories project was launched in the same call as the Factories of the Future FoF-11-2016 research and innovation projects, where six of them were focusing on digital platforms for factory automation (AUROWARE, DISRUPT, DAEDALUS, FAREDGE, SAFIRE and scalABLE4.0) and four projects were focusing on supply chain and logistics (COMPOSITION, DIGICOR, NIMBLE, vf-OS).

The digital manufacturing platform concept in its wider scope covers whole RAMI space and the mentioned projects fill different gaps within the reference architecture proving a set of building blocks for that purpose. With this complementary and incremental build up strategy, there are three other relevant projects (Industrial Data Space, ARROWHEAD, and Productive 4.0). Figure 1 shows the place that each project fills in the two-dimensional cross-section table of the RAMI 4.0 framework.

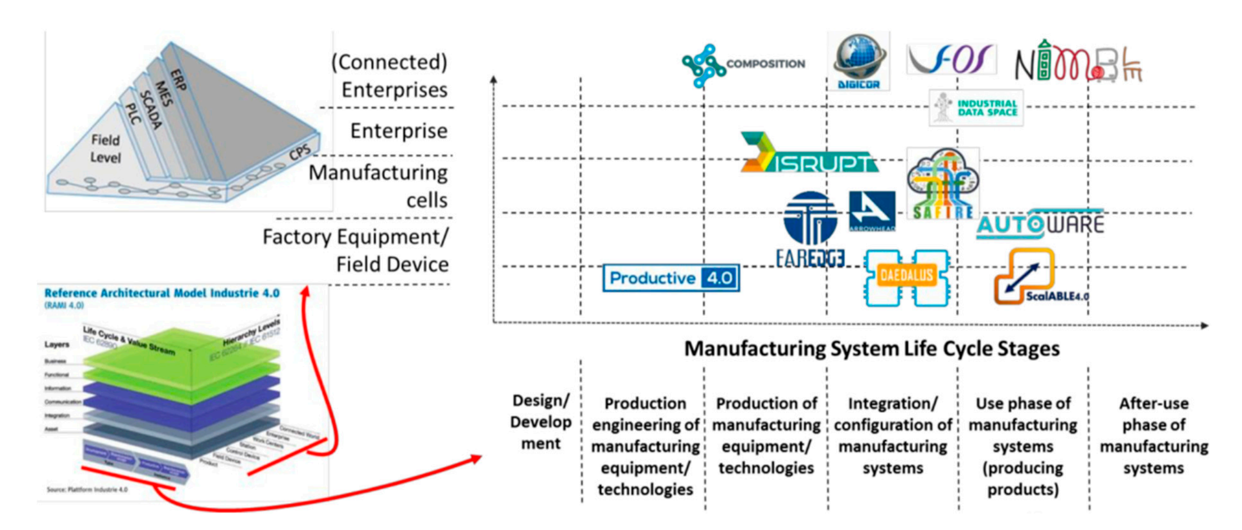


Figure 1. Positioning of digital platform related research and development (R&D) projects on RAMI 4.0. Source Reference [43] (p. 21).

In addition, DT-ICT-07 2018, the H2020 ICT call focused on Digital Manufacturing Platforms for Connected Smart Factories began three projects in January 2019 aimed to develop orchestrated open platforms ecosystem, atomized components, and digital enablers to meet the Industry 4.0 ZDM and lot-size-1 challenges.

4.4. *Digital Platform from Industrial Equipment Suppliers*

In addition to the efforts by leading IT vendors, industrial conglomerates (Siemens, GE, etc.), and the R&D initiatives, machine tool builders aim to transform their businesses digitally. For instance, by making use of data deriving from the machine tools they build, they develop predictive and prescriptive solutions for customers, improving machining performance, health and safety, energy-efficiency, business domain integration and so on. Their offer includes HMI software, production management software, machine and shop floor monitoring software, technical assistance software, etc. Usually, technology consultancy services with a global offer are necessary to be able to define the solution with the client. Therefore, industrial equipment suppliers are partnering with IT and consultancy companies.

Leading machine tool builders are investing more and more in digital platforms to provide a comprehensive solution to their customers:

DMG Mori [44] is a pioneer when it comes to digitization in machine tool construction. Under the key phrase "Integrated Digitization", DMG Mori with CELOS [45] is realizing a consistent strategy—starting with CELOS Machine, via CELOS Manufacturing up to the Digital Factory. DMG Mori started with CELOS, an operating and control system based on applications. Supported in ADAMOS [46], CELOS can become an open network and a digital market for the machine construction industry. ADAMOS relies on Microsoft Azure infrastructure.

Homag [47] machines have been connected to the plant level for a long time, they even have their own MES system. They started with their own digital platform that connected them to the cloud. Now, it is an open platform (Tapio) integrated in ADAMOS. The HomagGroup offers its customers solutions for digitized production with a complete software platform. They offer many services in the field of machines and production facilities, in addition to the corresponding control software.

Trumpf [48]: Stands for the digital business model supported in Truconnect as a smart factory platform that includes a comprehensive portfolio of consultancy, software and hardware resources. Axoom [49] provides a cloud monitoring platform for Trumpf machines but it is not exclusive to competitors.

Bosch [50]: Bosch Connected Industry bundles software and services for Industry 4.0 in a comprehensive portfolio called Nexeed.

Siemens [51]: Mindsphere is the cloud-based, open IoT operating system from Siemens that connects products, plants, systems, and machines, enabling you to harness the wealth of data generated by the Internet of Things (IoT) with advanced analytics. Mindsphere runs on top of Microsoft Azure or AWS infrastructures.

Fanuc [52]: FIELD (FANUC Intelligent Edge Link & Drive system) is the FANUC's open platform system that gives machine tool builders, robot manufacturers, and sensor and peripheral device manufacturers the freedom to develop their own applications. The target of the FIELD system connects each device within a factory, but also allows the flexibility to connect to upper host systems, such as ERP (Enterprise Resource Planning), SCM (Supply Chain Management) and MES (Manufacturing Execution Systems).

Schaeffler [53]: Schaeffler focuses its products in the digital world. Schaeffler has incorporated sensors, actuators, and control units with embedded software into these products. As a result, it is possible for these parts to collect and process valuable data on the condition of a machine and then convert this data into added-value services. With IBM as strategic partner, Schaeffler provides a digital platform for processing large amounts of data, generating valuable insight to transform operations. The Schaeffler cloud is a platform for end users to securely and reliably access data from their machines and equipment.

5. Conclusions

The review paper shows the concept and scope of digital manufacturing platforms from different perspectives combining technology and policy making, industry, and academia and the stakeholders that are involved on them as ecosystem.

The development of digital manufacturing platforms is in an early stage but supported in a mature IoT ground. Due to the broad scope of the concept, it has required the definition and development of a reference implementation, RAMI 4.0. In the current platform building context, it is not a matter of making choices for platform adopters but planning an incremental roadmap towards digital transformation. In this sense, the openness of the technological architecture is a must where state-of-the-art technologies regarding IoT, Artificial Intelligence, robotics, cloud or Big Data will be reused and integrated with interfaces described via open specifications. Platforms should aim for openness, avoiding lock-ins, preventing dominant positions of individual players, and compliance with standards and regulation.

Moreover, the openness of the digital manufacturing platform is a major issue as an enabler of digital ecosystems to become an AEP (application enablement platform).

It is remarkable that the role of the major IaaS (Infrastructure as a Service) providers is becoming more and more vertical or domain-oriented. The role of big players, such as Amazon or Microsoft, has been the provision of IoT and IT infrastructures with pay-per-use business models so far. Nowadays, these players are moving towards PaaS (Platform as a Service) services in manufacturing. This movement is being carried out accompanied by reference OEMs of prioritized industrial sectors.

In spite of the relevant advances achieved so far, there is still a lot to do in order to connect to additional services according to the 'plug-and-play' philosophy and considering the multi-sided ecosystem of service providers, platform providers and manufacturing companies, mechanisms for the commercial or open-source provision of the digital services through appropriate marketplaces, modularity of existing or in-development platforms of covering different "regions" of the RAMI framework, legacy system integration, overcoming semantic barriers, considering requirements of specific manufacturing sectors (process industry, consumer goods, capital equipment, etc.), etc.

The benefits of the fourth industrial revolution must be monetized for companies, to the extent that technology advances become reality. The definition and support of new business models based on

data will be the next big challenge in relation to digital platforms. All these issues outline future work in digital manufacturing platforms.

Author Contributions: Conceptualization, J.K.G. and E.U.; Methodology, J.K.G. and A.S.; Investigation, J.K.G., E.U., A.S. and G.U.; Resources, J.K.G., E.U., A.S. and G.U.; Data Curation, J.K.G. and E.U.; Writing-Original Draft Preparation, J.K.G. and E.U.; Writing-Review & Editing, A.S. and E.U.; Supervision, J.K.G.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wang, K. Intelligent Predictive Maintenance (IPdM) system—Industry 4.0 scenario. *WIT Trans. Eng. Sci.* **2016**, *113*, 259–268.
2. Muller, J.M.; Buliga, O.; Voigt, K.I. Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technol. Forecast. Soc. Chang.* **2018**, *132*, 2–7. [CrossRef]
3. Hermann, M.; Pentek, T.; Otto, B. Design principles for industrie 4.0 scenarios. In Proceedings of the IEEE 2016, 49th Hawaii International Conference on System Sciences (HICSS), Koloa, HI, USA, 5–8 January 2016; pp. 3928–3937.
4. Thoben, K.D.; Wiesner, S.; Wuest, T. Industrie 4.0 and smart manufacturing-a review of research issues and application examples. *Int. J. Autom. Technol.* **2017**, *11*, 4–16. [CrossRef]
5. Kagermann, H.; Helbig, J.; Hellinger, A.; Wahlster, W. *Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry, Final Report of the Industrie 4.0 Working Group*; Forschungsunion: Berlin, Germany, 2013.
6. Smart Manufacturing Leadership Coalition. Implementing 21st Century Smart Manufacturing, 2011, Workshop Summary Report. Washington, DC, USA. September 2010. Available online: https://www.controlglobal.com/assets/11WPpdf/110621_SMLC-smart-manufacturing.pdf (accessed on 13 May 2019).
7. Fujii, T.; Guo, T.; Kamoshida, A. A Consideration of Service Strategy of Japanese Electric Manufacturers to Realize Super Smart Society (SOCIETY 5.0). In *Knowledge Management in Organizations, Proceedings of the International Conference on Knowledge Management in Organizations, Zilina, Slovakia, 6–10 August 2018*; Springer: Berlin/Heidelberg, Germany, 1842; pp. 634–645.
8. Park, J.; Lee, J. Presentation on Korea smart factory program. In Proceedings of the International Conference on Advances in Production Management Systems, Tokyo, Japan, 7–9 September 2015; pp. 5–9.
9. Geissbauer, R.; Vedso, J.; Scharauf, S. PWC. 2016 Global Industry 4.0 Survey, Industry 4.0: Building the Digital Enterprise. Available online: https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf (accessed on 3 April 2019).
10. European Commission. Pillars of the Digitising European Industry Initiative. 2018. Available online: https://ec.europa.eu/digital-single-market/en/pillars-digitising-european-industry-initiative (accessed on 3 April 2019).
11. Schumacher, A.; Erol, S.; Sihn, W. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP* **2016**, *52*, 161–166. [CrossRef]
12. Liao, Y.; Deschamps, F.; Loures, E.D.F.R.; Ramos, L.F.P. Past, present and future of Industry 4.0—A systematic literature review and research agenda proposal. *Int. J. Prod. Res.* **2017**, *55*, 3609–3629. [CrossRef]
13. Theorin, A.; Bengtsson, K.; Provost, J.; Lieder, M.; Johnsson, C.; Lundholm, T.; Lennartson, B. An event-driven manufacturing information system architecture for Industry 4.0. *Int. J. Prod. Res.* **2017**, *55*, 1297–1311. [CrossRef]
14. Qin, J.; Liu, Y.; Grosvenor, R. A categorical framework of manufacturing for industry 4.0 and beyond. *Procedia CIRP* **2016**, *52*, 173–178. [CrossRef]
15. Erol, S.; Jäger, A.; Hold, P.; Ott, K.; Sihn, W. Tangible Industry 4.0: A scenario-based approach to learning for the future of production. *Procedia CIRP* **2016**, *54*, 13–18. [CrossRef]
16. The Economist. Siemens and General Electric Gear up for the Internet of Things. 2016. Available online: http://www.economist.com/news/business/21711079-american-industrial-giant-sprinting-towards-its-goal-german-firm-taking-more (accessed on 11 February 2019).

17. Chryssolouris, G.; Mavrikios, D.; Papakostas, N.; Mourtzis, D.; Michalos, G.; Georgoulias, K. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. *Digit. Manuf. Hist. Perspect. Outlook* **2009**, *223*, 451–462.
18. Chen, Y. Integrated and Intelligent Manufacturing: Perspectives and Enablers. *Engineering* **2017**, *3*, 588–595. [CrossRef]
19. GE Digital. *Predix: The Industrial Internet Platform*; White Paper; General Electric Company: Boston, MA, USA, 2016.
20. The ThingWorx IoT Technology Platform [Internet]. Needham: PTC. Available online: https://www.thingworx.com/platforms/ (accessed on 02 June 2019).
21. Feuer, Z.; Weissman, Z. Smart Factory—The Factory of the Future [Internet]. Sunnyvale: LinkedIn. Available online: https://www.linkedin.com/pulse/smart-factory-future-zvi-feuer?articleId=8390740796107302304 (accessed on 19 December 2016).
22. Alcácer, V.; Cruz-Machado, V. Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems. *Eng. Sci. Technol. Int. J.* **2019**, *22*, 899–919. [CrossRef]
23. Liu, C.; Xu, X. Cyber-physical Machine Tool—The Era of Machine Tool 4.0. *Procedia CIRP* **2017**, *63*, 70–75. [CrossRef]
24. Zhong, R.Y.; Xu, X.; Klotz, E.; Newman, S.T. Intelligent Manufacturing in the Context of Industry 4.0: A Review. *Engineering* **2017**, *3*, 616–630. [CrossRef]
25. Kusiak, A. Encyclopedia of Sustainable Technologies. *Smart Manuf.* **2017**, *7543*, 417–427. [CrossRef]
26. Wu, D.; Greer, M.J.; Rosen, D.W.; Schaefer, D. Cloud manufacturing: Strategic vision and state-of-the-art. *J. Manuf. Syst.* **2013**, *32*, 564–579. [CrossRef]
27. De Reuver, M.; Sørensen, C.; Basole, R.C. The digital platform: A research agenda. *J. Inf. Technol.* **2018**, *33*, 124–135. [CrossRef]
28. I-scoop. IoT Platform Definitions, Capabilities, Selection Advice and Market. Available online: https://www.i-scoop.eu/internet-of-things-guide/iot-platform-market-2017-2025/ (accessed on 11 May 2019).
29. Azure IoT. Available online: https://azure.microsoft.com/es-es/overview/iot (accessed on 17 June 2019).
30. IoT-Enable Your Business Applications. Available online: https://cloud.oracle.com/en_US/iot (accessed on 17 June 2019).
31. Cloud IoT Core. Available online: https://cloud.google.com/iot-core (accessed on 20 June 2019).
32. The Internet of Things Delivers the Data. AI Powers the Insights. Available online: https://www.ibm.com/internet-of-things (accessed on 20 June 2019).
33. AWS IoT Core. Available online: https://aws.amazon.com/es/iot-core (accessed on 19 June 2019).
34. Bosch IoT Suite. Available online: https://www.bosch-iot-suite.com (accessed on 17 June 2019).
35. Mori, M.; Fujishima, M.; Komatsu, M.; Zhao, B.; Liu, Y. Development of Remote Monitoring and Maintenance System for Machine Tools. *CIRP Ann.* **2008**, *57*, 433–436. [CrossRef]
36. Mori, M.; Fujishima, M. Remote monitoring and maintenance system for CNC machine tools. In Proceedings of the 8th CIRP Conference on Intelligent Computation in Manufacturing Engineering, Ischia, Italy, 18–20 July 2012.
37. Edrington, B.; Zhao, B.; Hansel, A.; Mori, M.; Fujishima, M. Machine Monitoring System Based on MTConnect Technology. *Procedia CIRP* **2014**, *22*, 92–97. [CrossRef]
38. EFFRA, The European Factories of the Future Research Association. Connected Factories. Available online: https://www.effra.eu/connectedfactories-project (accessed on 18 May 2019).
39. EFFRA, The European Factories of the Future Research Association. Digital Manufacturing Platforms. Available online: https://www.effra.eu/digital-manufacturing-platforms (accessed on 18 May 2019).
40. BMWi, Federal Ministry for Economic Affairs and Energy. Benefits of Application Scenario Value-Based Service. 2017. Available online: https://www.plattformi40.de/PI40/Redaktion/DE/Downloads/Publikation/benefits-application (accessed on 19 June 2019).
41. VDMA. RAMI 4.0 and Industrie 4.0 Components. 2016. Available online: https://industrie40.vdma.org/en/viewer/-/v2article/render/15557415 (accessed on 19 June 2019).
42. International Data Spaces. Available online: https://www.internationaldataspaces.org/ (accessed on 20 June 2019).

43. European Union, Brussels. Digitising European Industry: Working Group 2—Digital Industrial Platforms. 2017, p. 21. Available online: https://ec.europa.eu/futurium/en/implementing-digitising-european-industry-actions/report-wg2-digital-industrial-platforms-final (accessed on 19 June 2019).
44. European Commission. Digitising European Industry. Working Group 2. Digital Industrial Platforms. 2017. Available online: https://ec.europa.eu/futurium/en/system/files/ged/dei_wg2_final_report.pdf (accessed on 19 June 2019).
45. DMG MORI. Available online: https://es.dmgmori.com/productos/digitization (accessed on 19 June 2019).
46. ADAMOS. Available online: https://www.adamos.com (accessed on 4 June 2019).
47. HOMAG. Available online: https://www.homag.com/ (accessed on 4 June 2019).
48. TRUMPF. Available online: https://www.trumpf.com/es_ES/productos/fabricainteligente/ (accessed on 3 June 2019).
49. AXOOM. Available online: https://axoom.com/ (accessed on 9 June 2019).
50. BOSCH. Nexeed Software and Services for Production and Logistics. 2018. Available online: https://assets.bosch.com/media/en/global/products_and_solutions/connected_products_and_services/industy_40/bosch-connected-industry-brochure.pdf (accessed on 4 June 2019).
51. SIEMENS. This Is MINDSPHERE! Available online: https://new.siemens.com/global/en/products/software/mindsphere.html (accessed on 14 April 2019).
52. FANUC. Available online: https://www.fanuc.co.jp/en/product/field/index.html (accessed on 9 June 2019).
53. SCHAEFFLER. Available online: http://www.schaeffler.com/content.schaeffler.com/en/innovation/digitization/digitization.jsp (accessed on 19 June 2019).

